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TECHNIQUES FOR MEASURING BODY COMPOSITION

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Apparent body weight increases gradually as breathholding continues (Stevens *et al.*, 1946). Both of these considerations imply that precise timing is essential. In other words, no change in lung volume should occur between the time the underwater weight is observed and the time the procedure for determining RV is started. This means that breathholding should not be continued any longer than necessary or the proportions of N_2, CO_2, and O_2 in the lungs at the time RV is determined may be quite different than is usually assumed.

One of the important considerations in evaluating the reliability of a particular technique is the amount of variability that is observed when repeated measurements are made. In man, as in any biological specimen, physiological alterations confuse a strict interpretation of the differences between duplicate determinations. The following questions are not answered precisely: what variation is produced by biology, what by technique? Nevertheless, the standard deviation of the distribution of differences between duplicate measurements may furnish useful information about the reliability of the technique if experimental control reduces biological variability to a minimum. Table 3 shows the variation of differences between replicate determinations that has been observed for three methods used to determine RV in conjunction with underwater weighing. A reasonable value for the upper limit for the standard deviation of the difference distribution may be assumed to be 100 ml.

TABLE 3

VARIATION OF DIFFERENCES BETWEEN REPLICATE DETERMINATIONS OF RESIDUAL VOLUME

Source	Position	No. of double determinations	Method	Variation in RV (ml) *Δ
Rahn (1949)	Seated	182	O_2 Rebreathing	84
von Döbeln (1956)	Seated	121	H_2 Rebreathing	59
Brožek *et al.* (1953)	Seated	18	N_2 Washout	66
				78*

RV = Residual volume
*Δ = Standard deviation of the difference distribution
* = Submerged underwater

Gas in the Gastro-intestinal Tract (VGI)

One of the volumes not accounted for by the usual underwater weighing procedures is the volume of gas in the gastro-intestinal tract (VGI). Numerous methods for measuring VGI have been tried but most of these methods have failed to produce acceptable and un-

equivocal results. Table 4a shows some of the mean volumes that have been obtained with the various methods. The values range from 28 ml to 1330 ml. It is felt that the value of 1330 ml is much too high (Keys and Brožek, 1953; von Döbeln, 1956) because of inaccuracies

TABLE 4a

VOLUME OF GAS IN THE GASTROINTESTINAL TRACT

Investigator	Method	n	Mean Volume cc
von Döbeln (1956)	Underwater wt. in low pressure chamber	?	<100
Blair *et al.* (1947)	Plethysmograph	40	1330
Marshall *et al.* (1955)	Plethysmograph	?	115
Keys & Brožek (1953)	X-ray	21	(28)[1]

[1] Upper observed limit, 133 cc.

in the plethysmographic technique that was employed. Perhaps the best values for VGI have been obtained using a total body plethysmographic technique and an intra-gastric balloon. Recent evidence by Bedell *et al.* (1956a, 1956b) (Table 4b), who used this method for measuring VGI in a large series of patients and normals, suggest that the average VGI is 115 ml but can range from 0-500 ml among subjects and about 50-300 ml. from day to day in the same subject.

TABLE 4b

VOLUME OF GAS IN THE GASTROINTESTINAL TRACT

Investigator	Method	n	$\bar{x}$	s_x	Range
1) Bedell *et al.* (1956a)	Plethysmograph & Gastric Balloon	21	110	—	0-375
2) Bedell *et al.* (1956b)	"	32 (13 subj.)	115	127	0-456
3) Bedell *et al.* (1956b)	"	48	116	125	0-537

$\bar{x}$ = mean, ml
s_x = standard deviation
One subject measured on 10 different days, range 34-361 ml.

On the basis of the findings of Bedell *et al.*, it is proposed that a correction of 100 ml (BTPS) be used in the equation for calculating D_B in order to provide a more valid estimate of D_B on the average.[1]

[1] Water pressure on the abdominal area would reduce VGI as well as RV. If the subject is weighed underwater in the sitting position the effective pressure head of water would vary between 5 to 30 inches of water depending on the stature and position of the subject.

Thus, the equation (1) would become:

$$D_B = \frac{M_{B_A}}{\dfrac{(M_{B_A} - M_{B_W})}{D_W} - (RV + VGI)} \qquad (2)$$

where $VGI = 100$ ml ($BTPS$)

Other Errors

In addition to the variables discussed thus far, gas bubbles frequently adhere to the skin and hair on the body surface unless the tank is filled the night before. These bubbles can usually be wiped off by the subject. The combined volume of these bubbles probably would never exceed 10 ml even if no attempts were made to remove dissolved air from the bath water. Trapping of air in the hair of female subjects (with or without a tight bathing cap) poses a special problem.

Body Density (D_B)

Because the various errors that have been discussed thus far may partially summate or cancel, consideration should be given to the standard error of the difference distribution for the measurement we are actually interested in, namely, body density.

Table 5 shows the standard deviation of the difference distribution for replicate determinations of body density by several investigators. A total of 361 replicate determinations are included. Some investigators report much smaller standard deviations than others. Dr. Goldman[1] (personal communication) has since reported that his value 0.0043 gm/cm.^{3} actually the square root of the total error variance obtained from replicate measurements made on several subjects has been reduced to a value of about 0.002 with subsequent experience with his apparatus. This would reduce the range from 0.0004 to 0.0026. Most of these values are equal to or are below the value 0.0025 gm. cm.^{3} cited by Siri (1956) as acceptable in terms of utility in calculating body composition and specifically fat content.

At this point, the question might well be asked—Why has space been devoted to a discussion of the underwater weighing method when a more versatile method is available for determining body volume and body density? Reference is made to Siri's helium dilution body volume device. Part of the answer is that: 1) several underwater weighing

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[1] Environmental Protection Research Division, Quarermaster Research & Engineering Center, Natick, Mass.